EFFECTS OF THE GALILEO

CONSTELLATION

ON U.S. NATIONAL INTERESTS

GRADUATE RESEARCH PROJECT

Zannis M. Pappas, Major, USAF

AFIT/GMO/ENS/02E-8

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GMO/ENS/02E-8

EFFECTS OF THE GALILEO CONSTELLATION ON U.S. NATIONAL INTERESTS

GRADUATE RESEARCH PAPER

Presented to the Faculty of the Graduate School of

Engineering and Management of the

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the

Requirement for the Degree of

Masters of Air Mobility

Zannis M. Pappas, B.S., M.S.

Major, USAF

June 2002

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

AFIT/GMO/ENS/02E-8

EFFECTS OF THE GALILEO

CONSTELLATION

ON U.S. NATIONAL INTERESTS

Zannis M. Pappas, BS, MS
Major, USAF

Approved:

James T. Moore (Advisor)	Date

Acknowledgments

I would like to express my sincere appreciation to my graduate research sponsor, Mike Filler, Lt Col, USAF (Ret), and my graduate research advisor, James Moore, Lt Col, USAF (Ret). Their advice and guidance helped to launch this research and keep it on track.

Foremost, I am eternally grateful for the love and support of my family, relatives and friends. Their encouragement provided continuous inspiration and drive.

Zannis M. Pappas

Table Of Contents

List of Figures

Figure Page

<u>**List of Tables**</u>

Abstract

In 1973, the U.S. Department of Defense invested $12B to develop a space-based navigation system known as Global Positioning System (GPS). GPS provides free navigation and timing signals to worldwide users. Although GPS was originally developed as a military system, during the last decade, the GPS industry has exploded with new applications in transportation, mapping and time synchronization, thus becoming the newest “global utility”. GPS is the dominant player on the Global Navigation Satellite System market, which is expected to reach $50B by 2010. Driven by the success of GPS and the huge satellite navigation market potential, the European Union is planning on developing its own satellite system, called Galileo. Galileo will be under civil control and its performance would be similar to modernized GPS. Galileo users will have to pay a fee for Galileo’s premium service. The deployment of Galileo raises several military and commercial concerns that could affect U.S. national interests. Before Galileo becomes operational, United States representatives and their European counterparts must resolve many issues such as signal allocation, protection from unauthorized use of the signal, regulatory restrictions and interoperability of the two systems.

THE EFFECTS OF THE GALILEO

CONSTELLATION

ON U.S. NATIONAL INTERESTS

I. Introduction

In 1973, the U.S. Department of Defense (DoD) invested $12B to develop a space-based navigation system known as Global Positioning System (GPS). The constellation achieved full operational capability (FOC) in 1994 with the launch of the 24th satellite. Although GPS was originally developed as a military system, during the last decade, the GPS industry has exploded with new applications in transportation, mapping and time synchronization, thus becoming the newest "global utility". The Russian Federation has developed its own satellite navigation system, known as Global Navigation Satellite System (GLONASS). GLONASS achieved FOC in 1995, but since then, the constellation has degraded, leaving GPS as the dominant player in the Global Navigation Satellite System (GNSS) market.

The satellite navigation field is a growth industry, increasing annually at about 25 percent. The gross income for 2000 is estimated at $8.5B and is expected to rise to $17B by 2003. Driven by the success of GPS and the huge satellite navigation market potential, the European Union (EU) is planning on developing its own satellite system, called Galileo. Galileo is considered the European contribution to GNSS and its

performance would be similar to modernized GPS. The Galileo program is estimated to cost 3.4 Billion Euros, financed equally by both the public and the private sector.

U.S. companies currently enjoy almost a monopoly in the satellite navigation industry. The introduction of Galileo is expected to change this situation. In order to preserve the current status and for national security reasons, the U.S. government has taken several steps to satisfy the increasing demands of the worldwide navigation market and make the development of Galileo obsolete. The U.S. government and the European Union are the two major players in this market. Their decisions drive satellite design and, in turn, applications and user equipment manufacture.

The goal of this paper is to examine the effects of the proposed Galileo constellation on U.S. national interests. Chapter II reviews the literature associated with the satellite navigation industry. It provides some background information on satellite navigation and reviews the current status of the industry. The main focus of Chapter III is the future of the GNSS market. This chapter also provides an internal company analysis of U.S. and European companies involved in the space-based navigation market. Chapter IV analyzes the macro-environment, discusses the forces that drive industry competition and reviews the competitive strategies of the United States and the European Union. In addition, Chapter IV examines the strengths and weaknesses of GPS and Galileo, and provides recommendations. Finally, Chapter V is a conclusion along with an introduction of potential areas for further research.

II. Literature Review

History of Navigation

Since prehistoric times, people have been trying to figure out a reliable way to navigate on land and at sea. Cavemen used stones and landmarks to mark a trail when they hunted for food. The earliest mariners followed the coast closely to keep from getting lost. When navigators first sailed into the open ocean, they were following the stars. Unfortunately, the stars are only visible at night - and only on clear nights.

The next major developments in the quest for the perfect method of navigation were the magnetic compass, the sextant and the chronometer. The needle of a compass always points north, so it is always possible to determine the direction of someone's movement. The sextant uses adjustable mirrors to measure the exact angle of the stars, moon, and sun above the horizon. However, in the early days of its use, it was only possible to determine latitude (the location on the Earth measured north or south from the equator) from the sextant observations. In 1761, the development of a chronometer helped sailors determine their longitude (the location on the Earth measured east or west). For the next two centuries, sextants and chronometers were used in combination to provide latitude and longitude information.

In the early 20th century, several radio-based navigation systems were developed and were used widely during World War II. One drawback of using radio waves generated on the ground is that you must choose between a system that is very accurate but does not cover a wide area (like UHF TV), or one that covers a wide area but is not very accurate (like AM radio). As a result, scientists decided that the only way to provide

coverage for the entire world was to place high-frequency radio transmitters in space. These “man-made stars” are sending a high-frequency radio wave with a special coded signal that can cover a large area and still overcome much of the "noise" encountered on the way to the ground. This is one of the main principles behind the Global Positioning System (Aerospace Corporation, 2001). Satellite navigation is a unique field that has revolutionized our lives. Ground-based navigation aids can substitute satellites but only in a limited area. Furthermore, the timing signal provided by GPS represents a one-of-a-kind technology.

The Global Positioning System

The U.S. DoD developed the concept and general configuration for GPS in the early 1970s under a joint program involving all military departments. After program approval, DoD designated the U.S. Air Force (USAF) as the executive agent to manage and implement a developmental system. Subsequently, the USAF established the GPS Joint Program Office (JPO) at its USAF Space and Missile Systems Organization in Los Angeles, California. The original amount invested to develop this space-based navigation system was $12B. GPS consists of three segments: the space segment, the user segment and the control segment. (Figure 1)

The space segment consists of at least 24 satellites, and each satellite orbits the earth in 12 hours (semi-synchronous orbit) at a speed of 7,000 miles an hour. The satellites are positioned in six orbital planes (with nominally four satellites in every plane) 10,900 nautical miles (about 20,200 km) above the earth’s surface. These six orbital planes are equally spaced (60 degrees apart), and inclined at about fifty-five

degrees with respect to the equatorial plane. This configuration provides users with between five and eight satellites visible from any point on the earth.

The user segment consists of the GPS receivers and the user community. The GPS control segment consists of monitor stations located around the world (Hawaii and Kwajalein in the Pacific Ocean; Diego Garcia in the Indian Ocean; Ascension Island in the Atlantic Ocean; and Colorado Springs, Colorado); a Master Control Station at Schriever Air Force Base (previously called Falcon AFB) in Colorado Springs; and five ground antennas (Cape Canaveral, Acsension Island, Diego Garcia, Kwajalein and Colorado Springs) that broadcast signals to the satellites. The GPS control segment monitors satellite performance and commands the constellation. (Hurn, 1989:15)

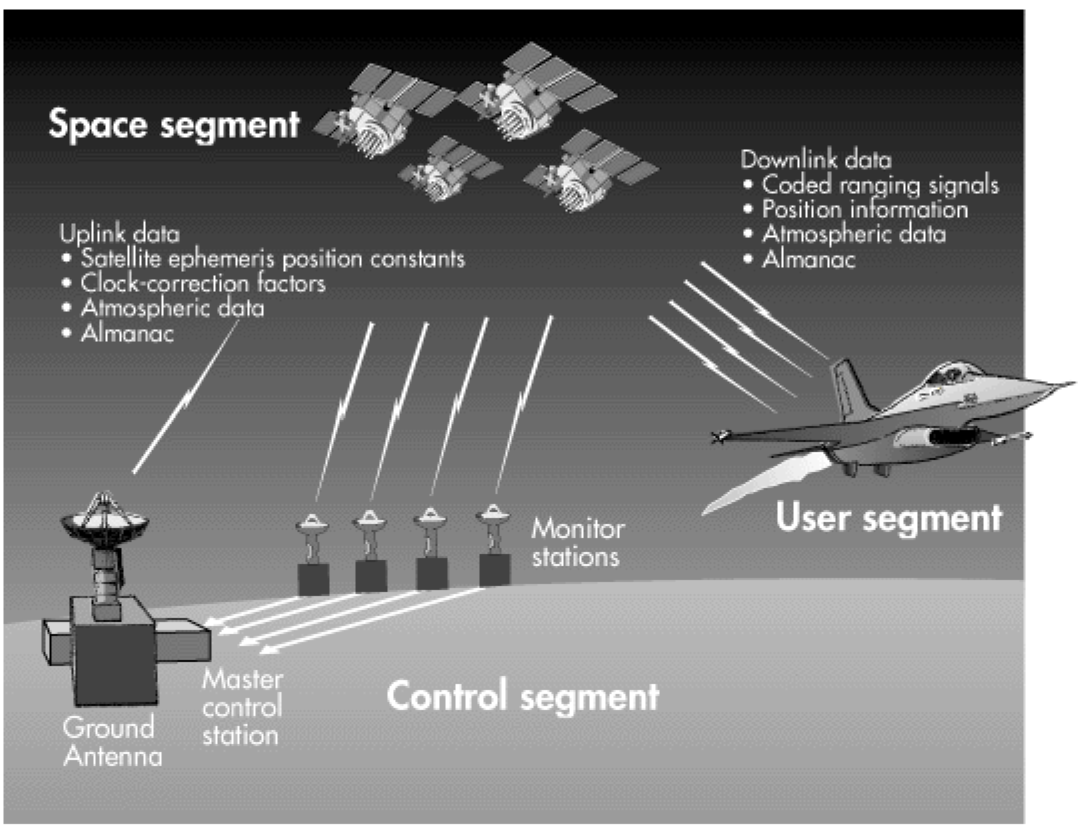

Figure 1. GPS Segments

The first GPS satellite was launched in 1978. The first 10 satellites were developmental satellites, called Block I. The last Block I satellite was launched in 1988. From 1989 to 1993, 23 production satellites, called Block II (Figure 2), were launched. In April 1995, GPS was declared fully operational, with a ground segment, a constellation of 24 operational satellites, and a variety of user equipment providing navigation services worldwide. Rockwell manufactured the Block I and Block II satellites. In 1996, Boeing purchased Rockwell's military and space division for $3.2 billion. The first of the next generation satellites (Block IIR) was launched in 1997. Lockheed Martin is the manufacturer of Block IIR satellites. The USAF acquired 21 of these satellites (the first Block IIR was lost during launch). As of today, there are 28 active GPS satellites, six Block IIRs and 22 Block IIs. The Delta II expendable launch vehicle is used to launch GPS satellites from Cape Canaveral Air Station, Florida. The Mean Mission Duration (MMD) of a Block II satellite is 9.6 years, of a Block IIA 10.23 years and of a Block IIR 10.62 years. MMD numbers is a very valuable tool to determine future launch schedule and other important policy issues (Althouse, 2002).

The 2d Space Operations Squadron (2 SOPS) at Schriever AFB, is responsible for day-to-day operations of GPS. For operational issues, the squadron is a part of the 50th Space Wing, which falls under the command of 14th Air Force (a Numbered Air Force), which in turn falls under USSPACECOM (a Unified Command). Air Force Space Command (AFSPC), an Air Force Major Command, is responsible to "organize, train and equip" 14th AF missions. AFSPC and USSPACECOM headquarters are at Peterson AFB, CO and 14th AF headquarters are at Vandenberg AFB, CA. 2 SOPS' unit mission description states that the squadron "Commands and controls the $2B, 24-satellite Global

Positioning System (GPS), the world's largest military satellite constellation. Operates and maintains all satellite payloads and subsystems plus a 24-hour worldwide ground network executing three distinct missions: navigation, precise time transfer, and nuclear detonation (NUDET) detection. Directly supports millions of military and civilian users worldwide".

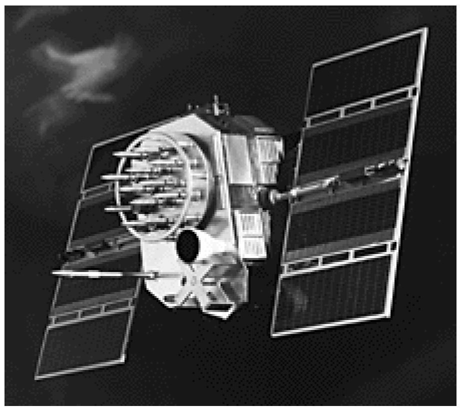

Figure 2. GPS Block II satellite

How GPS Works

GPS is based on knowing someone's distance from the satellites in space. The equation "Velocity times travel-time equals distance" is the foundation to determine positioning. Every GPS satellite continuously transmits two L-band frequency (1575.42 MHz [L1] and 1227.60 MHz [L2]) radio signals. Each signal carries precise time and satellite position data to GPS receivers on the ground or in the air.

The ground unit receives the satellite signal, which travels at the speed of light: 186,000 miles per second. Even at this speed, the signal takes a measurable amount of time to reach the receiver. In order to figure out exactly how long it took the signal to reach the receiver, GPS designers synchronized the satellites and receivers so that they generate the same code at exactly the same time. These complicated codes are called

"pseudo-random" codes and are repeated every millisecond. There are two separate forms of pseudo-random codes, one is called the "C/A code" (Coarse Acquisition) and the other is called the "P-Code" (Precise). The C/A Code modulates the L1 carrier phase and is the basis for the civil Standard Positioning Service (SPS). Civilian receivers use only the L1 frequency. The P-Code (Precise) modulates both the L1 and L2 carrier phases. The P-Code is encrypted into the Y-Code. Only authorized users with cryptographic keys can use the encrypted Y-Code. Military receivers use both frequencies to determine their position. They first acquire the C/A code on the L1 frequency, which is transmitted on a clear basis, and then the secure signals, the P/Y-codes on L1 and L2. The P/Y-Code is the basis for the Precise Positioning Service (PPS). When the receivers receive the codes from the satellite they look back and see how long ago the receivers generated the same code. The time difference is how long the signal took to get down to the receivers. The difference between the time the signal is sent and the time it is received, multiplied by the speed of light, enables the receiver to calculate the distance to the satellite.

Because radio waves travel at the speed of light, if the satellite and the receiver were out of sync by even 1/100th of a second, the calculated distance measurement could be off by 1,860 miles. In order to ensure proper time synchronization, GPS satellites are equipped with Cesium and Rubidium atomic clocks. These clocks are unbelievably precise and are considered as the most stable and accurate time reference man has ever developed. They keep accurate time to within three nanoseconds (0.000000003, or three billionths, of a second).

After a GPS receiver calculates its distance from the satellites, the exact location of these satellites is needed in order to determine positioning. The USAF places each satellite into a very precise orbit according to the GPS master plan. The orbits are known in advance and some GPS receivers have an “almanac” programmed into their computer’s memory, which tells them where in the sky each satellite will be at any given moment. Since the satellites go around the earth once every twelve hours, 2 SOPS has the chance to precisely monitor their altitude, position and speed through the worldwide system of monitor stations. Operators are looking for variations called “ephemeris” errors. These variations are usually very minor and are caused by gravitational pulls from the moon and sun and by the pressure of solar radiation on the satellite. Corrections are relayed back to the satellites, which in turn relay these minor corrections along with its timing information to worldwide users. To measure precise latitude, longitude, and altitude, the receiver must be in the view of at least four GPS satellites (Hana, 2000: 2-4).

GPS Errors

The ultimate accuracy of GPS is determined by the sum of several sources of errors. The contribution of each source varies depending on atmospheric and equipment conditions. GPS designers and operators have taken extra steps to ensure that every part of the system is as accurate as it can be. But as perfect as the system seems to be, there are a couple of sources of error that are very difficult to eliminate.

Perhaps the most significant of these errors arises from the earth’s ionosphere, a blanket of electrically charged particles 80 to 120 miles above the earth. These particles affect the speed of light and so affect the speed of the GPS radio signals. Even after the signals make it through the ionosphere, they have to encounter the earth’s atmosphere

where water vapors affect the speed of these signals. Although atmospheric propagation delay is less severe than the ionospheric one, a combination of both can introduce significant errors. The L2 frequency is used to measure the ionospheric delay by PPS equipped receivers. However, civilian users have no means to calculate ionospheric delays because they can only use the L1 frequency. As a result, the accuracy provided to the civil community is less than the accuracy provided to military users (Hurn, 1989:38-47).

Other sources of errors equally affecting PPS and SPS receivers are satellite clock errors, ephemeris errors and receiver errors. In addition, geometry of the satellites in view, can magnify or lessen all the previously mentioned uncertainties. 2 SOPS operators constantly monitor the atomic clocks and the ephemeris data. Adjustments are performed on a daily basis to ensure small deviations are eliminated. Having more the 24 properly positioned GPS satellites helps in terms of geometry. Therefore, DoD is maintaining an average of 28 operational satellites on orbit, in order to guarantee the minimum requirement of 24 (Filler, 2002).

Russian Space-Based Navigation

The Global Navigation Satellite System (GLONASS), is the Russian counterpart to GPS. In much the same manner as GPS, GLONASS is controlled by the Russian Ministry of Defense. The GLONASS system has two types of navigation signal: standard precision navigation signal (SP) and high precision navigation signal (HP). SP positioning and timing services are available to all GLONASS civil users on a continuous, worldwide basis and provide the capability to obtain horizontal positioning accuracy within 57-70 meters and vertical positioning accuracy within 70 meters.

GLONASS attained full operational capability in 1995 with a constellation of 24 satellites. On December 1, 2001, the Russian Federation successfully launched two standard Uragan spacecraft and one Uragan-M, the next generation satellite with a longer orbit lifespan and higher accuracy. This launch was the first in more than a year for the financially strapped program. As of May 2002, there are just seven operational satellites, out of a nominal constellation of 24. Russian space officials say they have the intention and the resources to fully restore the system during the next years. They hope to have 10-12 operational satellites by 2003, and a complete constellation by 2007 (GPS World, 2002:4).

Despite these optimistic statements, navigation industry analysts believe that the Russian government is focusing on providing launch services to commercial enterprises and to joint efforts with western firms. Maintaining a robust GLONASS system, especially when GPS provides free global navigation service, is not considered a top Russian priority, especially after the success the Russian Federation had in sales of their Proton launch vehicles on the world market. GLONASS is only a drain on precious and limited resources. In a final analysis, without some tremendous influx of outside capital, the future of GLONASS is doubtful past 2002 (Peloquin, 2000:8-9).

GPS Accuracy

As the sole owner/operator of GPS, the United States maintains complete control over the system. The original specifications of GPS called for two different services: the Precise Positioning Service and the Standard Positioning Service. Authorized users with cryptographic equipment and keys and specially equipped receivers use PPS. Authorized

users are the U. S. and Allied military, certain U. S. Government agencies, and selected civil users specifically approved by the U. S. Government.

The original specifications for PPS accuracy are:

- 22 meter horizontal accuracy
- 27.7 meter vertical accuracy
- 200 nanoseconds Universal Time Coordinated (UTC) accuracy

The latest improvements in the system have led to accuracies of less than 10 meters. Currently, the system provides precise navigation and timing services with accuracies two- to three-times better than the original requirements. These improvements are due mainly to the ingenuity of 2 SOPS operators at Schriever AFB.

The United States Air Force (USAF) retains the ability to manipulate GPS and its data and deny others access to it. For many years, the DoD intentionally degraded the accuracy of the C/A code using an operational mode called “Selective Availability” or SA. SA is essentially a method for artificially creating a significant clock error in the satellites that affects only civilian users. When implemented, it is the largest source of error in the GPS system, resulting in the Standard Positioning Service, used by the worldwide civil community.

The original specifications for SPS accuracy are:

- 100 meter horizontal accuracy
- 156 meter vertical accuracy
- 340 nanoseconds UTC accuracy (Hana, 2002)

GPS Accuracy without Selective Availability

In March 1996, a Presidential Decision Directive (PDD) established the Interagency GPS Executive Board (IGEB) to manage the Global Positioning System and its U.S. Government augmentations as a national asset. The IGEB is a senior-level policy making body chaired jointly by the Departments of Defense and Transportation. Its membership includes the Departments of State, Commerce, Interior, Agriculture, and Justice, as well as NASA and the Joint Chiefs of Staff. The Department of Transportation is responsible for the civilian applications of GPS, and the Department of Defense, and specifically the USAF, is controlling and financing the system.

The same PDD committed the U.S. government to discontinue the use of SA by 2006 with an annual assessment of its continued use beginning in 2000. On 1 May 2000, acting upon the recommendation of the Secretary of Defense and the IGEB, President Clinton ordered SA to be turned off as of midnight of that day. 2 SOPS operators promptly executed the President’s directive and provided civilian users of GPS with pinpoint accuracy up to ten times better than they previously received. Discontinuation of SA encouraged acceptance and integration of GPS into peaceful civil, commercial and scientific applications, as well as private sector investment in GPS technologies and services. Setting SA to zero has minimal impact on national security because DoD has demonstrated the capability to selectively deny GPS signals on a regional basis when U.S. national security is threatened. Since 2 May 2000, civil users of GPS have received accuracy almost as good as the one received by the authorized users. The difference is due to the existence of only one civil frequency (L1), versus the two frequencies (L1 and

L2) used for military applications that allows for ionospheric correction (Statement by the President, 1 May 2000).

It is very important to note that although Selective Availability decreases accuracy, it in no way denies service. The U.S. government guaranteed to provide GPS SPS navigational data, free of charge, to the entire world for peaceful, civil use.

Differential GPS

GPS is by far the most accurate global navigation system ever devised. But even its incredible accuracy can be improved by a technique called “Differential GPS” or DGPS. DGPS is based on the idea that if we place a GPS receiver on the ground in a known location, we can use it to figure out exactly what errors the satellite data contains. This receiver acts like a static reference point and it can transmit an error correction message to any other GPS receivers in the local area, and in turn, these receivers can use that error message to correct their position. With DGPS, we can achieve accuracies of better than a meter, thus bringing GPS into some surprising applications. The latest applications by surveyors have brought accuracies to the last centimeter. Their techniques are extensions of DGPS. With a GPS survey receiver, one surveyor can do the work of a whole team in a fraction of the time required by conventional techniques (Hurn, 1989:58-61).

The U. S. Coast Guard maintains a network of differential monitors and transmits DGPS corrections over radio beacons covering much of the U. S. coastline. The Coast Guard's maritime DGPS Service achieved Full Operational Capability on 15 March 1999. The system provides service for coastal coverage of the continental U.S., the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and a large part of the Mississippi

River Basin. The U.S. Coast Guard Navigation Center (USCG NAVCEN), located in Alexandria, Virginia, operates the Coast Guard Maritime DGPS Service and the developing Nationwide DGPS Service, consisting of two control centers and over 60 remote broadcast sites. The Service provides 10-meter accuracy in all established coverage areas. Typically the positional error of a DGPS position is 1 to 3 meters, greatly enhancing harbor entrance and approach navigation. In addition, the maritime DGPS service provides integrity alarms for GPS and DGPS out-of-tolerance conditions within 10 seconds of detection with availability of 99.7%. Many foreign nations are implementing standard DGPS services modeled after the U.S. Coast Guard's system to significantly enhance maritime safety in their critical waterways (USCG NAVCEN, 2002).

The U.S Coast Guard has recently contracted with the Raytheon Company's Technical Services arm for ten years of engineering, technical, maintenance, and support services for the Nationwide Differential Global Positioning System (NDGPS). The $76 million support contract will provide services needed to complete NDGPS build-out to an envisioned 81-site system, and to sustain it once completed. Currently, users apply NDGPS's improved accuracy in precision farming, vehicle tracking, and other surface transportation services. The Federal Railroad Administration wants a full NDGPS radio-beacon network for safety-of-life positive train control in terrain such as canyons that block GPS satellite signals (GPS World, January 2002).

Space Based GPS Augmentation Systems

The Federal Aviation Administration (FAA) and the Department of Transportation are developing the Wide Area Augmentation System (WAAS) program

for use in precision flight approaches. WAAS is a system of satellites and ground stations that provide GPS signal corrections, giving users up to five times better position accuracy (less than 3 meters accuracy). Currently, GPS alone does not meet the FAA's navigation requirements for accuracy, integrity and availability and is available only in North America. WAAS consists of approximately 25 ground reference stations positioned across the United States that monitor GPS satellite data. Two master stations, located on either coast, collect data from the reference stations and create a GPS correction message. This correction accounts for GPS satellite orbit and clock drift plus signal delays caused by the atmosphere and ionosphere. The corrected differential message is then broadcast through one of two geostationary satellites. Although WAAS has not yet been approved for aviation, the system is available for civilian use, such as for recreational GPS users. WAAS provides extended coverage both inland and offshore compared to the land-based DGPS (garmin.com, 2002).

The European Geostationary Navigation Overlay System (EGNOS) is the European contribution to Space Based GPS Augmentation Systems (SBAS). EGNOS is overseen by the European Space Agency (ESA) and involves 35 high-tech companies from 11 countries. Alcatel Space, a French-based telecommunications giant, is the prime contractor. When the program becomes operational in 2004, it will provide Europe-wide Category 1 precision approach capability under all-weather conditions. EGNOS will employ three geostationary satellites, 34 Ranging and Integrity Monitoring stations in 22 countries and four redundant Master Control Centers (in UK, Germany, Spain and Italy). In Asia, the Japanese are developing the Multi-Functional Satellite Augmentation System (MSAS) which like WAAS and EGNOS will provide GPS integrity data derived from

ground based monitoring stations and up-linked through geostationary satellites to the users. These three SBAS systems will provide the highest level of performance within Europe, the Continental United States and Japan (Spiller, 2001:2).

Military Applications of GPS

Since 1991, GPS has become the most significant force enhancement tool of the U.S. military. During Operation Dessert Storm only 15 GPS satellites were operational but their contribution to allied victory was paramount. In many respects, this was GPS's baptism in a high tempo operational environment. The most dramatic example of the value of GPS precision is the famous "Left Hook" of the 1990-91 Persian Gulf War. Until this time, deep desert operations were considered too difficult to perform. The Iraqis expected coalition forces to follow the Gulf coast and the Tigris-Euphrates valley. Coalition commander General Norman Schwartzkopf ordered eight US, British and French armored divisions and two airmobile divisions to accomplish a wide sweep through trackless desert. GPS receivers enabled tank units to move at 50 kilometers per hour without stumbling into one another at ranges precluding visual identification. Unsurprisingly, many Coalition commanders cited GPS as one of the most important technologies of the war. General Sir Peter de la Billiere, commander of all British forces in the Gulf, called GPS a "war-winner" (Hasik, 2001:2).

In 1991, coalition forces did not drop one GPS-guided bomb. The precision weapon of choice was Laser-guided bombs (LGBs). In order to use LGBs you must be able to see the target, which means you must have good weather. In 1995, over Bosnia, GPS-guided weapons were not available in large numbers, so the precision strikes with LGBs were often scrubbed for weather. The 1999 Kosovo war was the greatest test of

U.S. airpower up to then, in part because President Clinton and Congress had forbidden the engagement of U.S. ground forces. However, this time the U.S. military had at its disposal new devices called Joint Direct Attack Munitions (JDAMs). These are “dumb bombs”-mostly 2,000-pounders- retrofitted with an electronic “brain” and fins for steering. A JDAM bomb is programmed with the coordinates of its target and then, as it falls from the sky, it calculates its position in space and directs itself to the target by reading GPS signals. Previously developed “smart bombs” were based on Inertial Navigation Set (INS)-based guidance systems. However, INS performance degrades with distance from launch. Since GPS performance does not, it is ideally suited for long-range weapons guidance, thus providing an unprecedented all-weather precision strike capability (Barry, 2001:2-3).

Another promising new technology used during the 1999 Kosovo war, was the Predator. Predator is an unmanned aircraft that can take continuous video of the battlefield and beam it back to base. Because Predator’s field of vision was too narrow, operators could never be precisely sure where the drone was located as it was filming. As a result the aircraft had limited effectiveness in Kosovo. Now the Predator has a GPS sensor aboard and its precise latitude and longitude are registered at the bottom of every TV image it relays home. This feature enables commanders to have a “real time” awareness of the Afghan battlefield (Barry, 2001:2-3).

Recently, Defense Secretary Donald H. Rumsfeld has called the on-going war on terrorism the most accurate ever. As of April 2 2002, nearly 60 percent of the 22,434 bombs, missiles and other ordnance used in Afghanistan were guided to their targets by lasers or GPS satellites. Their effectiveness was about 90 percent. In the Gulf War, by

comparison, only 8 percent of the munitions were laser-guided. Airplanes have dropped 6,650 JDAMs, which has emerged as the weapon of choice due to its all-weather capability. That has depleted the inventory so dramatically, that Boeing, the bomb's manufacturer, is preparing to triple production to 3,000 units a month. JDAMs are so accurate that the Pentagon is now looking to speed up production of guided 500-pound and 250-pound bombs, instead of the current 2,000 and 1,000-pound bombs. Smaller bombs have two main advantages: reduce the risk of collateral damage and bombers could carry more of them and strike many additional targets on one mission (Schmitt, 2002:1-3).

During the last decade, GPS has grown to support nearly every aspect of U.S. warfighting. Today, no significant military operation is conducted without it, and no system is built without GPS. GPS has enabled a combination of precision strike with standoff range, all-weather performance, and operational flexibility-all at a very low cost.

Civilian Applications of GPS

The GPS system was originally developed to meet military needs of the Department of Defense, but during the last decade it has become a "global utility" along with power, water, natural gas and telecommunications. The 1 May 2000 Presidential decision to discontinue SA has skyrocketed GPS civil applications. All civilian users currently enjoy accuracies of less than 10 meters and GPS is usable everywhere except where it is impossible to receive the signal such as inside most buildings, in caves and underwater. Some of these applications include: all means of transportation (air, road, rail, and marine navigation), precision agriculture and mining, oil exploration,

environmental research and management, construction, recreation, telecommunications, electronic data transfer and emergency response.

The most common airborne applications are for navigation by general aviation and commercial aircraft. At sea, GPS is also typically used for navigation by recreational boaters, commercial fishermen, and professional mariners. Land-based applications are more diverse. In the transportation area, vehicle and cargo tracking is one of the fastest-growing GPS applications. GPS-equipped fleet vehicles, public transportation systems, delivery trucks, and courier services use receivers to monitor their locations at all times.

The scientific community uses GPS for its precision timing capability and position information. Surveyors use GPS for an increasing portion of their work. GPS offers cost savings by drastically reducing setup time at the survey site and providing incredible accuracy. Basic survey units, costing thousands of dollars, can offer accuracies down to one meter. More expensive systems are available and can provide accuracies to within a centimeter.

Recreational uses of GPS are almost as varied as the number of recreational sports available. Anyone who needs to keep track of where he or she is, to find his or her way to a specified location, or know what direction and how fast he or she is going can utilize the benefits of GPS. GPS is now commonplace in automobiles as well. Some basic systems are in place and provide emergency roadside assistance at the push of a button (by transmitting your current position to a dispatch center). More sophisticated systems that show your position on a street map, are also available. Currently these systems allow a driver to keep track of where he or she is and suggest the best route to follow in order to reach a designated location.

In addition to more accurate position information, the accuracy of the time data broadcast by GPS has improved to within 40 billionths of a second. Such precision may encourage adoption of GPS as a preferred means of acquiring Universal Coordinated Time (UTC) and for synchronizing everything from electrical power grids and cellular phone towers to telecommunications networks, banking transactions and the Internet. For example, with higher precision timing, a company can stream more data through a fiber optic cable by tightening the space between data packets. Using GPS to accomplish this is far less costly than maintaining private atomic clock equipment.

GPS is also helping to save lives. Many police, fire, and emergency medical service units are using GPS receivers to determine the police car, fire truck, or ambulance nearest to an emergency, enabling the quickest possible response in life-or-death situations (Aerospace Corporation, 2001:3-8).

GPS currently affects the everyday life of people throughout the world, often without them even knowing it. But as some have said, “you ain’t seen anything yet” (Shaw, 2001:3).

The Satellite Navigation Market

GPS is a critical technology for individuals and businesses around the globe. There are more than 4 million GPS users worldwide, and the market for GPS applications is expected to double in the next three years. The GNSS market (primarily GPS) is a growth industry, increasing annually at about 25 percent. The 2000 gross income is estimated at $8.5 B, is expected to rise to $17B by 2003 and exceed $50B in 2010. Since 1997, more than one million GPS receivers have been produced each year. Over the 2000-2009 decade, the US government expects to receive $6-7B from the individual

federal income taxes of those working in the GPS industry. This amount of money is enough to cover the cost of the entire GPS system (satellites, boosters, launches, control segment and operations). The ten-year cost for GPS has been placed at about $5B (McDonald, 2000:15).

III. Methodology

Future GPS Upgrades

The basic GPS signals that we use today and for which millions of receivers have been designed and produced were basically established in the early 1970s. After 25 years, it appears reasonable to reassess GPS in the context of the tremendous technological advances that have occurred during this period. For the past several years, high-level officials both from the civil and military communities have strongly advocated modernizing GPS.

Since the introduction of GPS, the civil community wanted two things: first the removal of SA and second, the addition of a second civil signal frequency for ionospheric compensation. On May 2, 2000, President Clinton's Executive Order removed SA. For defense applications, reliance on the C/A codes to acquire the P/Y codes was undesirable from a military prospective. If an adversary is using the civil signal, then those signals may need to be denied through jamming or other means. For this reason, defense planners want the capability to directly acquire the secure signals. One way to accomplish this is to place a new military code (M-code) signal separated in the spectrum from the C/A codes. Because there is no additional spectrum in the Radionavigation Satellite Service (RNSS) part of L-band, the obvious solution is to place C/A codes on L2

in the same manner they had been placed on L1. Unfortunately, the L2 band does not have the same level of protection from interfering signals as the GPS L1 band. High power radars and other emitters are co-located in that part of the spectrum. The Federal Aviation Administration (FAA) has therefore refused to accept this band for aviation safety applications (McDonald, 2001:1-2).

The first phase of the current GPS modernization plan is to modify the last 12 Block IIR satellites (now designated as Block IIR-M) with the following characteristics:

- 2nd civil frequency on L2
- M-Codes added to L1 and L2

The second civil frequency will provide better accuracy to civilian users and the new M-Code will improve signal processing and provide jamming resistance. Lockheed Martin is the primary contractor for this modification. The first modified IIR-M delivery is scheduled for 2003, with launches scheduled through 2006. The MMD for Block IIR-M satellites is estimated to be at 8.57 years (Sirak, 2002:1).

At the 2000 World Radio Conference (WRC) of the International Telecommunications Union (ITU), in Istanbul, Turkey, the region of the Aeronautical Radionavigation Services (ARNS) band centered at 1176.45 MHz was allocated for a GPS L5 band supporting safety-of-life applications. The civil L5 capabilities will not be incorporated into the modified Block IIR-M because of the spacecraft's power limitations. The Block IIF follow-on satellites have sufficient power to accommodate all Block IIR-M capabilities and the third civil frequency on L5. Specifically:

- 2nd civil frequency on L2
- M-Codes added to L1 and L2

- 3rd civil frequency on L5
- Crosslink Communications

A key feature on the Block IIF satellite is the capability for satellite-to-satellite communications through the use of Ultra High Frequency crosslink. 2 SOPS operators will be able to command and control multiple satellites using a single satellite in view, including satellites out of view of a ground antenna. The USAF has committed to purchase six Block IIF satellites and plans on buying six more. Block IIF satellites are scheduled for delivery in 2005 with launches scheduled through 2009 with Boeing being the primary contractor. The MMD for Block IIF satellites is estimated to be at 11.35 years (Rafferty, Lewis, Occhi, 2000:2562-2564).

GPS III is the third phase of space modernization. Boeing and Lockheed Martin are studying the Block III spacecraft under USAF contracts. GPS III will have the following capabilities:

- 2nd civil frequency on L2
- M-Codes added to L1 and L2
- 3rd civil frequency on L5
- Crosslink Communications
- Spot Beam capability
- 60 seconds integrity monitoring capability

GPS III encompass the capabilities of the IIR-M and IIF and includes a new high-power military code (M-code) signal. Additional spot beams will be able to put more power in areas where operations are conducted. GPS III satellites will have up to 300 times the transmission power of the current GPS constellation and provide a superb jamming

resistance. In addition, DoD requires that Block III vehicles will be able to notify users within 60 seconds of their failure or out of tolerance condition compared to 30+ minutes today. The USAF is exploring ancillary missions for the GPS III constellation, including monitoring the tracking of friendly forces, referred to as “blue force tracking”. Like all previous satellites, the Block III, will have sensors to support NUDET detection in the atmosphere or in space. If accelerated, the first GPS III satellite launch is scheduled for 2009 (Sirak, 2002).

In addition to space segment modernization, major modifications of the control segment are underway and expected to be complete by 2005 with Boeing and Lockheed Martin as the two primary contractors. These upgrades will make GPS comparable with the planned European Galileo constellation, especially in the area of civil applications. The addition of a second civil frequency on L2 and the third safety of life frequency on L5 will give worldwide civilian users a free of charge access to an extremely accurate navigation and timing signal (Gibbons Glen, 2000:10).

The European Space-Based Navigation System

In an effort to compete with the United States, the European Union (EU) plans on developing its own navigation system, called Galileo. Galileo is considered the European contribution to the GNSS, currently dominated by GPS. Galileo is the joint project of the European Commission and the European Space Agency to deploy a new infrastructure based on a 30-satellite constellation, to provide positioning and timing services. On December 7, 1999, the European Commission signed several contracts worth millions of euros to define Galileo’s overall structure. At the early stages of the project, the EU

acknowledged the contributions of GPS to global economy, but they also pointed out that there are three serious concerns about GPS:

- No guarantee of continuous service provided by its operators. Europeans are extremely concerned that such an important system as GPS is controlled by the U.S. military.
- GPS system provides moderate accuracy (70 to 100 meters) for civil users
- There is no "integrity-monitoring" built into the GPS system: e.g. users are not informed immediately of errors that occur (Galileo-pgm, 2001:2).

The second European concern no longer exists. As of 2 May 2000, SA was turned off and civil users currently receive accuracies of less than 10 meters. Furthermore, the GPS modernization plan will increase civilian services. Unfortunately, the timeline of these capabilities lag behind the envisioned Galileo operational date. Regarding the third European concern, integrity monitoring is incorporated in Block III GPS satellites. Under an accelerated schedule, the first Block III launch is scheduled for 2009, one year later than Galileo's FOC. These issues will be examined in more detail later in this paper.

Following on from the unanimous conclusions of the Barcelona European Council on 13-14 March 2002, the Council of Transport Ministers released the € 450m needed to develop Galileo. "Europe has finally taken the political decision to launch this strategic program. Today we are seeing the creative side of Europe," declared Mrs. Loyola de Palacio, the Commission Vice-president responsible for transport and energy. "This is good news and it shows the European Union's capacity to carry out an ambitious industrial project that will create 150,000 highly qualified jobs and generate income of

some €10bn a year. It will help Europe to maintain its autonomy, its sovereignty, its technological capacity and control of its knowledge," she concluded.

The EU is aggressively moving forward with the Galileo project. At an estimated cost of 3.4 B€ (about $3.1 billion) for design and deployment, Galileo would be the most significant infrastructure project by the European Union to date. Financing this project will require public and private support.

There are three successive phases of the Galileo program:

- Development and Validation phase (2002-2005)
- Deployment phase (2006-2007)
- Operating phase (2008 onwards)

Galileo will be Europe's own global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civilian control. It will be interoperable with GPS and GLONASS. A user will be able to take a position with the same receiver from any of the satellites in any combination. By offering dual frequencies as standard, however, Galileo will deliver real-time positioning accuracy of less than three meters. It will guarantee availability of the service under all but the most extreme circumstances and will inform users within seconds of a failure of any satellite. This will make it suitable for applications where safety is crucial, such as running trains, guiding cars and landing aircraft. In order to ensure global coverage, the fully deployed Galileo system consists of 30 satellites (27 operational + 3 active spares), positioned in three circular Medium Earth Orbit (MEO) planes in 23616 km altitude above the Earth, and at an inclination of the orbital planes of 56 degrees with reference to the equatorial plane. This architecture provides the best performance, particularly at high latitudes and the

lowest possible cost. Command and Control of the constellation will be the responsibility of two Galileo Control Centers (GCC) located in Europe, and 15 worldwide up-link stations.

The Galileo system will provide the following services:

Open Service: The GALILEO Open Service will provide to users free of charge positioning, navigation and timing signals with horizontal accuracy of 4 meters and service availability close to 99%. This service will be suitable for mass-market navigation applications, such as in-car navigation and applications of positioning with mobile telephones. Performance will be similar to GPS, but better performances could obviously be easily obtained by dual constellation usage. This service will not provide integrity monitoring.

Commercial Service (Open Service + Commercial Data): Encrypted data will be available within the Open Service signals to provide a Commercial Service. The Commercial Services will provide added value services on payment of a fee. Access will be controlled at the receiver level, using access protection keys. Typical value-added services, which could be provided on a commercial basis, include service guarantees, GALILEO and GPS integrity warnings, precise timing services and the provision of ionospheric delay models and local differential correction signals for extreme- precision position determination. The main applications will concern professional users who are ready to pay for a service guaranteed by the GALILEO operator, notably in the areas of geodesy and in activities involving customs and excise operations, network synchronization, sea fleet management, vehicle fleet management, road tolls, etc. There will be controlled access to this service for end-users and the providers of value-added

services. In fact, controlled access will enable revenue to be collected from users who are subscribers.

<u>Safety-of-Life Service (Open Service + Integrity Data):</u> The Safety Of Life Services will provide highly secure, high-integrity, certifiable services, suitable for critical applications. This service will be offered to users who are highly dependent on precision, signal quality and signal transmission reliability. It will need to offer a very high level of integrity and, consequently, to provide the user with a very rapid warning of any possible malfunctions. It will need to be certified in accordance with the regulations applicable to the various modes of transport. This service will require specialized receivers providing access to this enhanced-quality signal. The relevant revenues will be generated by providing controlled access to the signal for such users as air traffic controllers, air transportation companies, public network managers, rail companies, road traffic controllers, the customs and excise authorities. The Safety-of-Life Service will provide a global warning of a loss of integrity within a defined time-to-alarm limit and have an availability of above 99.9%. Combination of this GALILEO service either with current GPS capabilities augmented by EGNOS corrections, or the future modernized and EGNOS integrity-only, will support CAT-I performance and offer the prospect of sole means navigation.

<u>Public Regulated Service</u>: This service will have the accuracies and availability of the Safety-of-Life Service; however, it will be limited to public controlled applications only. It will provide resistance to interference, jamming and accidental aggressions. The Public Regulated Service will use protected frequencies, it will be encrypted, and it will have an availability of over 99%, even in crisis situations. This service will have

applications in the following areas: civil protection, law enforcement, governmental activities, some regulated or critical energy, transports and telecommunications applications, and economic and industrial activities that are deemed of strategic interest for Europe.

Search and Rescue Service: The GALILEO Search and Rescue service will allow users in distress to be located instantaneously with a very high accuracy, and will provide an acknowledgement of reception to the distress user. Vehicles will be fitted with beacons, which, having been activated in the event of an emergency will send an alerting signal to a rescue center. An acknowledgement that the signal has been received and logged will immediately be sent back to the stranded person. Availability of this service will be greater than 99%.

Out of the GALILEO definition studies, four frequency bands have been retained for the GALILEO signals. A tentative allocation of the five GALILEO navigation signals into the frequency bands has also been made on the basis of the transmission of four carriers.

- E5 and L5, covering the range 1164 MHz to 1215 MHz. Within this band, the use of 24 MHz of spectrum is being considered for supporting the Open and Safety of Life Services
- E6, 1260 to 1300 MHz. Within this band, the use of 30 MHz of spectrum is being considered, to accommodate the signals for the Public Regulated Service (PRS) and the Open (Commercial-encrypted, TCAR) Service

- E2, 1559 to 1563 MHz. This band would accommodate a signal for the Public Regulated Service.
- E1, 1587 to 1591 MHz. This band would accommodate a signal for the Open and Safety of Life Service.

Alternative frequency plans are also under evaluation to address the sharing of bands with GPS and GLONASS. When evaluating those alternative plans, interoperability and performance are two major issues to consider (Campagne and Tytgat, 2001:1255-11263).

The Galileo system will provide civil users a signal with very high reliability, a positioning accuracy of less than 4 meters and availability greater than 99%. With the exception of the open service, all other Galileo services provide system integrity monitoring. This is the paramount difference between the GPS and Galileo systems. The commercial and public services will be encrypted and more accurate than the open service. In a way, this mirrors the U.S. policy of denying the most accurate and secure data to all but military users (Commission Communication, 1999:4-16).

Internal Company Analysis

In the area of satellite navigation, the two major players are the United States and the European Union. Today, there is absolutely no “free market” competition among American and European aerospace companies. The US companies (Lockheed Martin and Boeing) will receive contracts for future GPS upgrades and the European companies will receive the contract to build and operate Galileo. Due to the nature of the space business (high risk, unique designs), the developmental cost is much higher than the cost to operate the system (normally 80/20 split). Traditionally, governments provide cost-plus contracts in order to protect the companies from uncertainties. Both Lockheed Martin

and Boeing have an excellent record with GPS. Block II and Block IIA spacecrafts are lasting longer than anticipated and the Block IIR satellites (first launched in 1997) are performing better than expected. Therefore, the US government has complete confidence in the ability of its contractors to carry out future GPS upgrades. The financial situation of these two aerospace giants and the cost-plus contracts mean they have the resources to conquer the technological challenges of modernizing GPS.

The European team of companies that makes up Galileo Industries formally inaugurated the new company in Brussels at the end of May 2000. The group includes Alcatel Space, Alenia Spazio and Astrium. Astrium is a joint venture owned 50% by DaimlerChlysler Aerospace and 50% by Aerospatiale and BAE Systems. Astrium owns 50% of Galileo Industries and Alcatel and Alenia own the other 50%. Alcatel Space has extensive experience in space-based navigation systems and ground segment operations. Alenia already has a small satellite plant in Rome where the Globalstars satellites were integrated. Astrium's has done well with its communications satellites. Already, there are 60 companies engaged in the Galileo program, as contractors to the three prime companies.

Galileo Industries' experience in the space business is not as strong as the experience of their American counterparts at Lockheed Martin and Boeing. However, there is no doubt they have the technological capabilities to complete such an ambitious project as Galileo. The biggest question in the satellite navigation industry is whether the EU will be able to raise private funds "upfront", before the system yields any revenues. This would become even harder if the Galileo project falls behind schedule and the US keeps GPS modernization on schedule (Bulloch, 2000:45).

IV. Results and Analysis

Macro-Environment and Industry Analysis

The biggest driver of the satellite navigation industry is the US government. Its policy and funding of GPS drives applications and product development. The US companies enjoy a virtual monopoly in the market, especially when there is no substitute for global space-based navigation and timing signals. Lockheed Martin and Boeing are the two prime contractors for the space and control segment with several suppliers, mainly of raw material. Out of 46 existing manufacturers of GPS receivers, only six are located outside the USA, and they use licenses from US producers. Competition from the Russian Federation is very weak and expected to diminish within the next few years. Worldwide civil users are the second most important force in the industry. Demands for better accuracy and stronger signal influenced decision-makers to proceed with an aggressive GPS modernization program.

The European Union, with its Galileo project, poses the major threat to the US dominance of the satellite navigation market. Currently there is a race between the US and the EU to satisfy users requirements and control the growing market. The Galileo "threat" created healthy competition in the industry and accelerated GPS modernization. Regardless of the future of Galileo, the entire world will benefit from the US/EU rivalry.

Many analysts called the 1990s the GPS decade. The question is what will we call the next decade. The GNSS Decade or even the Galileo Decade? Will Galileo become the "next Airbus"? Would we really have so much discussion about GPS modernization, if Galileo were not appearing over the horizon? Regardless of Galileo's

future the next decade will clearly be the "Decade of GNSS Users". There is no doubt that the entire world will benefit from the US/EU rivalry (GPS World, 1999).

The U.S. Strategy

Title 10 of U.S. Public Law, Subtitle A, Part IV, Chapter 136, Section 2281 calls the infrastructure of GPS as "vital to the effectiveness of United States and allied military forces and to the protection of the national security interests of the United States." Furthermore, it states: "In addition to having military uses, the Global Positioning System has essential civil, commercial and scientific uses … It is in the national interest of the United States for the United States to support continuation of the multiple-use character of the Global Positioning System"

On 7 March 2002, the U.S. State Department issued a statement regarding the government's official GPS policy. It was an effort to respond to European criticism about military control of the system, possibility of being cut off in case of crisis, and having civil applications disrupted. The State Department's statement emphasizes:

> "It has been U.S. policy since 1983 to provide GPS signals to civil users worldwide free of direct user fees. This policy has been supported by both Republican and Democratic Administrations and enjoys strong bipartisan support from Congress and there are no plans to change it. GPS is operated by the U.S. Air Force, but managed by IGEB. The IGEB is co-chaired by the Departments of Defense and Transportation and includes representatives of six other civilian departments and agencies. The United States is committed to providing uninterrupted service to civil users around the world. The U.S. military has contingency plans for denying access to the GPS signals to adversaries in specific areas of conflict, but to date this has never been done. GPS service continued without interruption, for example, during the Gulf War and the Kosovo and Afghanistan conflicts. In addition to providing free signals, the United States makes the civil GPS signal specifications available to the public at no charge. This enables businesses, scientific institutions, and government entities anywhere in the world to develop products, services, and research tools on an equal basis. The United States has launched an extensive modernization program to provide even better service to GPS users. More than one billion dollars has been

> committed to implement this program over the next several years. The first step was the discontinuation of Selective Availability, the process whereby the civil signals were intentionally degraded, in May 2000. This improved the accuracy of the GPS civil service from 100 meters to 10-20 meters. The next step involves new satellites that will broadcast two new civil signals: one of which will be introduced in 2003, the other in 2005. The added signals will increase the robustness of the civil service and improve accuracy to 3-5 meters. Additional upgrades are being planned for the next generation of satellites, known as GPS III. Users who need even greater accuracy and integrity can take advantage of government augmentation services, such as the Wide Area Augmentation System (and similar European and Japanese systems), the Local Area Augmentation System, commercial augmentation services, and advanced processing services. These services allow millimeter-level accuracy."

GPS Strengths and Weaknesses

The single most important strength of GPS is that the U.S. government, as the steward of this important system, has made a commitment to provide satellite navigation signal free of charge to the entire world for peaceful use only. GPS is a well-established system backed by the U.S. government. In addition, future upgrades will address the constantly increasing needs of the civil community. Civilian companies need only to concentrate on expanding the uses of GPS and to develop user equipment capable of processing signals broadcasted on L1, L2 and L5 frequencies. There is no need to invest in the space and control segment as long as the US government remains committed to maintaining a robust GPS constellation.

According to the civil community, the biggest drawback of GPS is the fact that it is controlled by the US military. As a result, military applications take precedence over civilian ones and GPS must often compete against non-positioning and timing systems (i.e. aircrafts, missiles, tanks and submarines). Experts believe that if GPS were instead funded and managed as a national positioning and timing service, we would realize

greater increase in service much earlier than the current modernization program (Lewis, 2000, 6).

The elimination of selective availability increased accuracy, but all users are still very vulnerable to service interruption due to the weak military and civilian signals. GPS signals can be easily jammed. Lack of integrity monitoring and guarantee of service are the other two major weaknesses of the system. Future satellite upgrades will address the integrity problem (GPS III), but the U.S. government has no intention to guarantee service.

A serious drawback of GPS relates to significant delays in civil capabilities planned for the civil sector. If we assume that the current modernization plan remains on schedule and with an average of 3 launches per year (which has been the normal number for the GPS program), Initial Operation Capability (IOC) and FOC for various civil capabilities is as follows:

Table 1. Timetable for GPS civil capabilities

	IOC (18 satellites)	FOC (24 satellites)
2 civil frequencies	2008	2010
Safety of Life	2012	2014
All capabilities	2016	2018

The GPS constellation will reach the point of having 30 GPS III satellites in 2020. Based on the current GPS modernization plan and the Galileo plan, these two spacecrafts are almost identical in terms of capabilities. Assuming a two-year delay in the Galileo program, the Europeans will have a 30-satellite constellation by 2010. A similar 30 GPS

III constellation would not be reached until 2020. If the decade of delay between Galileo and GPS capabilities occur, it would possibly force many users to take advantage of services provided by Galileo and not from GPS. This is a serious weakness of GPS especially when we assume an on schedule development of IIR-M, IIF, a two-year acceleration of GPS III and a two-year delay in Galileo development (McDonald, 2001:2807).

The European Strategy

As far back as the early 1990s, the European Union saw the need for Europe to have its own global satellite navigation system. The conclusion to build one was taken in similar spirit to decisions in the 1970s to embark on other well-known European endeavors, such as the Ariane launcher and the Airbus. The European Commission and European Space Agency joined forces to build Galileo, an independent system under civilian control which will be guaranteed to operate at all times.

There are four main arguments for the development of Galileo: political, social, technological and economic. The Galileo project is aimed at ending Europe's reliance on a military system, which has the possibility of being cut off. Europeans want to protect their independence and sovereignty. A European owned and operated satellite navigation system will improve safety of transportation, have environmental benefits and provide better and new services to Europeans. Developing and operating the Galileo constellation will lead to technological improvements and explore the synergy of a number of technologies.

However, the most important reason for developing Galileo are the economic benefits. According to a recent study, this window of opportunity gives Galileo an

estimated worldwide GNSS market size of 1.8B users in 2010 and 3.6B users in 2020. Another recent analysis indicates that Galileo has a cost/benefit ratio of 4.6, which is higher than any other infrastructure project in Europe and this only takes into account benefits from the air and sea transport sectors. Nevertheless, other studies support the case that further benefits will arise from route guidance, improved personal emergency service, management of taxis and ambulances, less pollution by reduction of travel times and creation of 150,000 jobs.

Europeans expect a mobility growth of 2% per year during the next decade with a much higher growth in mobility-related applications. The size of the European satellite navigation market in 1999 was 1 B Euros and is expected to reach 6 B Euros by 2005, (see Table below) (Commission Communication, 1999, 34).

Table 2: The Satellite Navigation Market

(In Billions of Euros)

	1999	**2005**	**2015**	**2020**
	GPS	**GPS**	**GPS + Galileo**	**GPS + Galileo**
Europe	1	6	7	11
World			22	42

In 2005, the road vehicle navigation market is estimated to reach 2 B Euros or 1/3 of the total European market. In 2015, in a projected GPS/Galileo environment, all vehicle applications will reach 12.6 B Euros out of a total world market of 22B Euros. This figure is expected to almost double by 2020. By developing Galileo, it is very obvious

that the EU wants a bigger share of this market, which is currently dominated by GPS and US companies.

Galileo Strengths and Weaknesses

Galileo represents a golden opportunity for European companies to enter the lucrative satellite navigation market. The project is based on the needs of the civil community and is specifically designed to satisfy the constantly increasing need for better accuracy in positioning and timing. As currently planned, it will provide better performance than GPS, especially in urban environments and for a service fee integrity monitoring and guarantee of service. Major improvements are expected in continuity, availability per day, outage time and integrity. Also, by placing satellites in orbits at a greater inclination to the equatorial plane than GPS, Galileo will achieve better coverage at high latitudes. This will make it particularly suitable for operation over northern Europe, an area not well covered by GPS.

According to the European Commission for Energy and Transportation the Cost/Benefit Analysis (Galileo Program, 2000:58) for the next two decades is as follows:

Total economic benefits	€62 B
Total social benefits	€12 B
Total benefits	€74 B
Total costs (3.4 B + operations)	€6 B

Internal Rate of Return: 75%

Although Galileo looks great on paper, such an ambitious project will face developmental and financial challenges. Many analysts question the ability of the EU to

raise public and private funds of this magnitude especially when GPS proceeds with an aggressive modernization plan. GPS is funded exclusively by the U.S. DoD budget, while Galileo must demonstrate economic viability: the operator must recover costs to develop and maintain the system. The European Private Sector must contribute €1.5B. Obviously the key question is: what is the balance between investment, risk and return? The premium Galileo signal will be available for a service fee. It is almost certain that many professional users would ask the question: "Why pay a fee when the US government offers the modernized GPS signal for free?"

Opportunities and Risks for the United States and the European Union

Currently, through GPS, the United States dominates the GNSS market. With no changes to the current situation, GPS will become the undisputed worldwide navigation and timing standard for at least the next twenty years. U.S. companies will retain their competitive edge over foreign competition, in an almost monopolistic market.

When the Europeans first announced their plans to launch their own satellite system, many people in the GPS community wondered what the real reasons behind Galileo were. Should we believe the Europeans when they claim sovereignty issues, and that they "don't trust the Americans", who can cut off GPS service in case of war? For a nation who has sent its sons and daughters to Europe twice this century to defend the European continent from the nightmare of Totalitarianism and Nazism these are harsh statements. For a nation, which essentially rebuilt Europe from the ashes of World War II and spent billions of dollars protecting them from the threat of communism, these statements really hurt. Especially when you wear the uniform of our great democratic nation. The reason the EU is in the position today to develop Galileo is because the

United States gave them GPS and protects democracy and free-market competition. Despite the emotional reaction and the lack of appreciation we felt, the truth is that Galileo makes sense for Europe. It creates thousands of high tech jobs, and it has huge revenue potential. Independence is not the true reason behind Galileo (we only wish the EU would finally admit it). Europeans know that we will never turn GPS off, simply because the entire world depends heavily on it. GPS was not denied during the Gulf War, Kosovo and Afghanistan conflicts. Furthermore, when our homeland was attacked on September 11, 2001, the constellation remained fully operational and we never even considered employing SA (Filler, 2002).

With Galileo, the European Union will have at its disposal an extremely reliable and accurate navigation system completely under civil control. For the EU, the current situation poses a threat to European independence and economic growth. Continuation of the status quo for the Europeans means missing a golden opportunity. On the other hand, committing €3.4B to a project that is expected to provide a cost/benefit ratio of 4.6, is considered a great business opportunity. By European standards, Galileo is not expensive. Its price is equivalent to that of "some 150 kilometers of semi-urban motorway or the cost of just one track of the main tunnel for the future high-speed rail link between Lyon and Turin" (European Commission, 2002:4).

The biggest risk for Europe is a combination of Galileo developmental and employment difficulties, cost overruns, lack of on-time private investment, while GPS modernization remains on schedule or is even accelerated. This combination of events would diminish the interest of the civil community for Galileo applications and would make its development obsolete. How likely is this scenario? A project of the Galileo's

magnitude would certainly experience technological difficulties. The big question rests with accelerating GPS modernization. Historically, every major GPS program has experienced a delay of one year for every two to three years of planned program (McDonald, 2001:2806). Unless the U.S. government remains committed not only to keep GPS modernization on schedule but also accelerate it, Galileo's future is secure.

The U.S. government has serious concerns with a possible Galileo development. These concerns are focused on two areas: military and civil.

Military Concerns: According to the 11 January 2001, report of the Commission to Assess United States National Security Space Management and Organization, (also known as "Space Commission"), "the U.S. is more dependent on space than any other nation…and is an attractive candidate for a "Space Pearl Harbor"…the ability to restrict or deny freedom of access to and operations in space is no longer limited to global military powers. Knowledge of space systems and the means to counter them is increasingly available on the international market". The Space Commission's report states that one of America's interests in space should be to "Develop and deploy the means to deter and defend against hostile acts directed at U.S. space assets and against the uses of space hostile to U.S. interests" (Space Commission Report, 2001:13-15).

Today GPS is the glue that binds together modern military operations. No other technology since nuclear weaponry has had such a dramatic influence on military strategy. The immense capabilities of GPS have prompted militaries around the world not only to adopt it for their own systems, but also find a way of combating it (Hasik, Rip, 2001:2406).

Recognizing the importance of GPS in military operations, and in an effort to avoid a "Space Pearl Harbor", AFSPC has been developing a concept called Navigation Warfare (NAVWAR), which is based on:

- <u>Protect</u> the GPS signals so U.S. and Allied forces have access to a precise navigation and timing signal. The development of the M-code will give us this capability. Even if an enemy jams the L1 C/A code, M-Code will give us the capability of direct P/Y code acquisition. We also need to be able to burn through jamming. The spot beams on GPS III will make it more difficult to jam GPS.
- <u>Prevent</u> adversaries from using the PPS. In case of enemy's use of GPS for hostile acts, we retain the capability of turning SA on. Also, the USAF has demonstrated the ability to degrade the GPS signal on a regional basis by jamming L1 C/A.
- <u>Preserve</u> the civilian uses of GPS while conducting military operations (Filler, 2002)

NAVWAR has to balance civilian capabilities and military applications. The more capabilities the civil community receives, the harder it becomes to conduct NAVWAR. The U.S. government, as the owner of GPS has been able to balance these conflicting interests. A space-based navigation system built for civil applications, controlled by foreign civil authorities, and driven to create revenue will make NAVWAR at least very expensive, and at worst, impossible. Especially, if Galileo and GPS use the same frequencies, as some plans reveal.

A recent RAND study reached the conclusion that "the Galileo program could negatively affect U.S. defense interests, given the possible need for additional technical

capabilities to use the signal aboard U.S. military platforms as well as Brussels' interest in pursuing a fee-based service for using precision navigation signals … significant military policy and operational disputes could arise from competing political or commercial interests, as well as from the added costs of equipping or refitting military platforms with new navigation signal receivers capable of using signals from both the U.S. and European systems (Rand, 2001:75).

Shortly before the European Transport Council met in December of 2001, Deputy Secretary of Defense Paul Wolfowitz sent a letter to EU defense ministers, expressing his "concerns about security ramifications for future NATO operations if the European Union proceeds with Galileo satellite navigation services that would overlay spectrum of the GPS military code signals". The letter argues that Galileo overlays "will significantly complicate our ability to ensure availability of critical GPS services in time of crisis or conflict and at the same time assure that adversary forces are denied similar capabilities". Mr. Wolfowitz encouraged EU defense ministers to convey his concerns to their respective transport ministers. Three months later, the European Transport Council released the € 450m needed to develop Galileo (GPS World, 2002:2).

The final U.S. military concern relies on its ability to defend against Galileo-guided bombs. Today there are over 70 countries with anti-ship cruise missile capability. Converting these to GPS-guided coordinate attack weapons is not a technically difficult matter. (Wiedemer, 2002:2413) Defending against these missiles is impossible especially without prior knowledge. But under appropriate intelligence notification or at later stages of the conflict, the U.S. military has demonstrated the capability of locally jamming GPS civil frequencies without affecting military capabilities. However, if these missiles are

Galileo-guided, jamming Galileo signal without prior coordination could be taken as an act of war against the EU (Filler:2002). If the U.S. seeks coordination with Galileo civil authorities, then the question is not only if the Europeans would allow it, but also how long it would take.

Civil Concerns: In civil issues, the major concern for the U.S. government is the risk of losing the revenue produced by the healthy American GPS industry. With the deployment of Galileo, the economic balance of power will shift towards European manufactures. Although worldwide navigation and timing users will enjoy tremendous benefits, that would be at the expense of the U.S. industry. A projected 10 year Galileo lead over similar GPS capabilities will drive applications and receiver design towards Galileo, not GPS.

At this point, it is unclear what kind of regulations the EU would impose in order to generate revenue for the Galileo program and attract private investment. Will Galileo use become "mandatory" in order to fly in European air space? If so, will U.S. military aircraft be exempt? Will the EU put taxes on all satellite navigation receivers sold in Europe (including GPS receivers)? Unfavorable answers to some of these questions will seriously endanger the economic viability of the U.S. navigation industry.

Recommendations

The Heritage Foundation, an influential conservative "think tank" in Washington D.C., recently issued a report on homeland security that urges inclusion of GPS in the nation's critical infrastructure and recommends creation of a National Program Office (NPO) to operate the system with the Department of Defense as the lead agency. Presumably, a GPS NPO would create a centralized budgetary and policy focal point in

the White House and it would supervise the activities of the IGEB. An NPO appointed by the president would enable better management of not just GPS itself, but the system of systems that grow from it. (GPS World, 2002:2)

The U.S. government must determine means and methods to better coordinate GPS with the Galileo program. It is a U.S. national interest to ensure Galileo technical parameters are compatible and interoperable with GPS. Issues such as frequency overlay, access to Galileo specifications, and regulatory restrictions must be resolved before Galileo becomes operational. Users should be free to choose which system or combination of systems best fits their needs. The United States would be opposed to anything that would degrade civil or military GPS signals and diminish the nation's ability to deny access to adversaries in time of crisis.

GPS modernization should be accelerated. The anticipated 10-year gap between similar Galileo and GPS capabilities could create a major threat to U.S. economic interests. Additional funding must be allocated to ensure military and civil users receive increased capabilities. The only chance the U.S. has to make Galileo development obsolete is an accelerated modernization schedule. Launching spacecraft on "anticipated need" should be changed to launching for capability. A larger modernized constellation (some 30-36 satellites), augmented with DGPS and SBAS, would make a strong statement in the international community regarding America's commitment to preserve the military and civilian uses of GPS.

V. Conclusion

.

During the last fifteen years the Global Positioning System has become the world's newest utility. GPS was originally designed as a military system, is provided free of charge, and has revolutionized transportation and telecommunications. The United States wants to continue its dominance both economically and militarily. Driven by GPS's success, the European Union is developing its own space based navigation system, called Galileo. Galileo would be under civilian control and financed by the public and private sector. Its performance would be comparable to modernized GPS, and for a service fee, it would provide integrity monitoring to authorized users. The Europeans, by deploying Galileo, are hoping to capture a big share of the growing GNSS market and improve their infrastructure. However, they run the risk of huge upfront costs, program delays and competing with an established system. Attracting private funds is a big gamble, especially when private investors must contribute over €1.5B.

The development of Galileo and the expected GPS upgrades would have tremendous benefits in many areas. Having two very accurate global satellite navigation systems would further improve quality of life. The United States must remain committed to modernizing GPS. Any delays would make the Galileo case stronger and increase private funding of the program. There are many U.S. national security concerns with the development of a civilian-controlled global navigation system. The U.S military could lose its ability to deny enemy access to precise navigation data and Galileo-guided precision bombs could be almost impossible to defend. Space dominance is a US national priority and any space system deployed by other nations must be taken very

seriously. The U.S. government is currently involved in negotiations with the European Union concerning GPS/Galileo compatibility, interoperability, frequency allocation, regulatory restrictions, and many other issues. Politicians, industry executives and trade representatives are discussing what type of institutions and structures should manage this new “global utility”. One thing is for sure: The United States will not give up the prize of space dominance without a good fight.

As we get closer to the projected Galileo operational date and as GPS modernization progresses, we need to re-evaluate the effects of Galileo on the U.S. national interests. This should be an on-going effort because world affairs constantly change. The more information we have, the better decisions we will hopefully make. As stewards of GPS, we need to see the “big picture” of this global utility. This is not an easy task, and requires the ability to see the “other side of the coin”. Without a doubt, Galileo has caused many headaches in Washington, where the Pentagon is jealously protecting a monopoly that lies behind the “smart weapons” revolution of the last decade. The best course of action is cooperation with the EU and improvement of GPS capabilities. After all, free competition is a fundamental principle of American democracy.

Bibliography

2nd Space Operations Squadron Unit Mission Statement, 2000

Aerospace Corporation, 2001. ***www.aero.org***

Althouse Matthew, Major (Ret), U.S. Air Force Space Command, Directorate of Operations, Peterson Air Force Base, Colorado Multiple personal Interviews. January-May

"A moment of truth." *Economist.* ***http//www.economist.com.*** 2 May 2002

Barry, John. "A New Breed Of Soldier," *Newsweek*, 10 December 2001

Bulloch Chris, 2000. "Galileo Industries Open For Business**"**, *Interavia Business & Technology*, June 2000

Canny Joseph, "Directions 2001 GNSS Greets a New Millennium**"**, *GPS World,* December, 2000

Campagne Pascal and Tytgat Luc. "Galileo: taking the next step," *ION GPS,* 11-14 September 2001, Salt Lake City, UT

Commission Communication,1999. "Commission Communication to the European Parliament and the Council on GALILEO**"**

Filler Michael, Lt Col (Ret), U.S. Space Command, Peterson Air Force Base, Colorado Multiple personal Interviews. January-May 2002

"Galileo, An Imperative for Europe," European Commission, Directorate General for Energy and Transport, 2002

"Galileo on the Brink Delay Builds Tensions," *GPS World,* 1 January 2002

Galileo Program, 2001, ***www.galileo-pgm.org***

Gibbons Glen, 2000. "Something Wonderful**"**, *GPS World*, September 2000, Vol. 11 Issue 9

GPS World. "Directions 2000"

Hana Peter, 2000. ***www.colorado.edu***

Hasik James M. and Rip Michael Russell "GPS at War: A Ten-Tear Retrospective," *ION GPS*, 11-14 September 2001, Salt Lake City, UT

"Heritage Security Report Urges GPS Changes," *GPS World*, February 2002

Hurn Jeff, 1989. *GPS: A Guide to the Next Utility.* Sunnyvale, CA: Trimble Navigation

Lewis Kirk L, "Directions 2001 GNSS Greets a New Millennium", *GPS World*, December, 2000

McDonald Keith D, "Directions 2001 GNSS Greets a New Millennium", *GPS World*, December, 2000

McDonald Keith D. "A Future GNSS Concern on the Modernization of GPS and the Evolution of Galileo," *ION GPS*, 11-14 September 2001, Salt Lake City, UT

Peloquin Perry, 2000. "An assessment of the United States' Policy concerning GPS in light of current and planned changes to the GNSS environment", Georgetown University

Rafferty Gary, Lewis Rob, Occhi Tony, 2000. "Modernization of the GPS Satellite Constellation", *ION GPS*, 19-22 September 2000, Salt Lake City, UT

"Report of the Commission to Assess United States National Security Space Management and Organization," January 11, 2001

Schmitt, Eric. "Improved U.S. Accuracy Claimed In Afghan Air War," *New York Times*, 9 April 2002

Sirak Michael, "USA Sets Sights On GPS Security Enhancements", *Jane's Defense Weekly*, January 16, 2002

Shaw Mike, "Directions 2001 GNSS Greets a New Millennium", *GPS World*, December, 2000

"Space Developments", RAND, October 11, 2000

Spiller John. "Galileo plus GPS – Opportunities," *ION GPS*, 11-14 September 2001, Salt Lake City, UT

"Statement by the President regarding the United States' decision to stop degrading Global Positioning System Accuracy", *The White House, Office of the Press Secretary*, May 1, 2000

U.S Coast Guard, 2002. ***www.navcen.uscg.gov***

"What is WAAS?" ***http//www.garmin.com***

Wiedemer Michael. "Proliferation," *ION GPS*, 11-14 September 2001, Salt Lake City, UT

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
07 06 2002	Graduate Research Paper	May 2001 - Jun 2002

4. TITLE AND SUBTITLE

Effects of the Galileo constellation on U.S. national interests

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Zannis M. Pappas, Major, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Institute of Technology
Graduate School of Engineering and
Management (AFIT/EN)
2950 P Street, Building 640
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GMO/ENS/02E-08

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

HQ AFSPC/DO
150 Vandenberg Street, Suite 1105
Peterson AFB, Co 80914

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

In 1973, the U.S. Department of Defense invested $12B to develop a space-based navigation system known as Global Positioning System (GPS). GPS provides free navigation and timing signal to worldwide users. Although GPS was originally developed as a military system, during the last decade, the GPS industry has exploded with new applications in transportation, mapping and time synchronization, thus becoming the newest "global utility". GPS is the dominant player of the Global Navigation Satellite System market, which is expected to reach $50B by 2010. Driven by the success of GPS and the huge satellite navigation market potential, the European Union is planning on developing its own satellite system, called Galileo. Galileo will be under civil control and its performance would be similar to modernized GPS. Galileo users will have to pay a fee for Galileo's premium service. The deployment of Galileo raises several military and commercial concerns that could affect U.S. national interests. Before Galileo becomes operational, United States representatives and their European counterparts must resolve many issues such as signal allocation, protection from unauthorized use of the signal, regulatory restrictions and interoperability of the two systems.

15. SUBJECT TERMS

Global Positioning System, Satellites, Galileo, Global Navigation Satellite System

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
U	U	U	UU	62	LtCol Stephan P. Brady (937) 255-6565 x4367

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18